Reliability Issues with Deep Submicron Interconnect

J.R. Lloyd, Jet Propulsion Laboratory, Pasadena CA

The relentless pursuit of compliance with Moore's Law has led us to finer geometries than thought possible only a few years ago. Although limits are appearing on the horizon in some areas, we have not yet approached theoretical limits to the size of conductors. Undoubtedly limits exist, but, until we approach a string of atoms as a wire, or find a suitable superconductor that can operate at high temperature and with high critical current densities, we will be using metal structures similar to those we are employing today.

Electromigration has always been the main concern in metallization reliability. Presently we are using current densities at least two orders of magnitude higher than those used in "bulk wires" and high performance designers are continuing to demand more and more juice through smaller and smaller straws.

In an effort to improve performance and reliability, the industry has made a paradigm shift of sorts by introducing copper metallization to replace aluminum alloys. Cu has a resistivity about half that of the Al/Cu alloys it is replacing, providing a doubling of speed all things being equal. In addition, interlevel dielectrics with low dielectric constants (low-K) are being introduced to further increase performance.

These improvements will have the effect of permitting higher levels of integration. This will allow faster data transfer and the ability to perform more functions at lower power, both of which are important in the design of spacecraft systems.

The use of low-K dielectrics and Cu metallization is not free of reliability issues. Along with their more desirable properties, both materials have properties that may prove troublesome to reliability, design, and manufacturing process engineers. Other emerging schemes, like SOI, will have additional issues that will need to be addressed.

As an example, there exists a nearly one to one correspondence with low dielectric constant and low thermal conductivity. In addition, low-K dielectrics are notoriously permeable to metal ion diffusion. The challenge will be to insure against intralevel and interlevel leakage as well as allow high current density coupled to lower heat conduction. Joule heating and the attendant temperature gradients will become limiting factors in performance.

Although Cu metallization should be more resistant to electromigration based on the higher melting temperature, peculiarities in their material properties make "rules of thumb" invalid. In addition, the lack of a self limiting natural oxide makes the Cu process much less forgiving than those using Al and its alloys.

Exotic alternatives to the present business as usual, such as SOI and high-K gate materials will offer new challenges as well. New solutions to new problems will be required as we try to dissipate heat from upper levels through poor thermal conductors and make connections to inherently unstable materials.

This is particularly important when viewed in the context of our unique mission. Reliability must be absolute and must be long term. Also, the environment of space poses challenges not found in terrestrial applications. For example, the suitability of low-k dielectrics to the vacuum of space must be considered and studied.

This presentation will review the state of the art in the understanding of electromigration failure in Al/Cu and in Cu conductors with a view towards the problems to be faced in the near future as we delve into the world of deep submicron (< 0.10 μm) conductors wirh low-k inter- and intra-level dielectrics capable of very long term reliability.